X-Ray Astronomy Research

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The thrust of the group's experimental research focuses on the development of detectors for x-ray astronomy. Two balloon flight instruments are currently being built, each incorporating new techniques developed in-house and each based on gas-filled proportional counters. The first of these, the Marshall Imaging X-Ray Experiment, No. 2, (MIXE2[1]) detector, utilizes special gas mixtures and construction materials and incorporates a novel microstrip electrode array, fabricated using microlithographic processes, which greatly improves the detector performance over conventional (discrete wire) proportional counters. An in-house development program, coupled with facilities provided by outside vendors, has led to the production of very large area devices (30 cm by 30 cm) one of which will be flying in the Spring of 1997 from Fort Sumner, NM, aboard a high-altitude balloon for x-ray astronomy observations.

The second instrument is a hard x-ray imaging polarimeter which utilizes an intensified CCD camera to image the photoelectron tracks produced by x-ray interactions.[2] It makes use of a special kind of gas counter, an optical avalanche chamber, which produces extremely large quantities of light photons ($>10^7$) under x-ray irradiation. Analysis of the initial ejection direction of the photoelectron permits a measure of the polarization of the incident x-ray photon. After extensive initial tests, a final design of a flight instrument has been completed and many of the components are either on order or in-house. The full-up instrument is scheduled to be completed by mid 1997.

To date, our flight experiments have been flown on a gondola in collaboration with Harvard College Observatory, but work is underway to develop an MSFC gondola. This will incorporate a novel pointing system, the heart of which is an attitude determination technique based on the global positioning system. By determining the relative x, y and z positions of several antennae around the gondola, the true orientation of the gondola can be ascertained and folded into the control loop to give pointing accuracies of a few arc minutes.

Various research projects support or spin off from the balloon flight programs and may lead to flight instruments in their own right. Typical of these is an investigation of the properties of ultra-high-pressure (50 to 100 atm) xenon ionization chambers that can extend the energy range of a conventional low-pressure (1 to 5 atm) gas-filled detector up to much higher energies (MeV region). Several prototype instruments have already been built and tested.[3] Similarly, we are investigating liquid xenon as a detection medium, using microstrip and microgap techniques developed for gaseous detectors. Liquid xenon is potentially very attractive as it is 500 times more dense than gas and hence offers much greater absorption capabilities. This large increase in density also results in the potential for much improved spatial resolution and the possibility of enhanced energy resolution. A small prototype chamber and associated gas liquification/purification system has recently been constructed and tests are underway. Finally, as a potential payload for future mini satellites, we are developing a Thomson scattering polarimeter sensitive over an energy range from 10 keV to 20 keV.[4] Polarization measurements are notoriously difficult to make and demand long observation times which in turn necessitate a dedicated mission. As the scattering polarimeter is simple in concept and combines low weight with low-power consumption, it is ideally suited to future lightweight, low-cost, fast-turnaround missions.

Another major research effort is the development and production of Wolter-1 x-ray optics using electroformed-nickel replication (ENR) off an electroless-nickel-coated aluminum mandrel. Our goals are to develop improved techniques for figuring, polishing, and coating the mandrel, plating and separating the mirror shell, controlling contamination, and testing the optic in x rays. Production of a replicated optic begins by turning a stress-relieved high-purity aluminum cylinder close to the desired optical figure. This mandrel is then plated with a thin (typically 0.16 mm) electroless-nickel/phosphorous layer, and machined to the precise optical figure. The mandrel is then polished (goal: micro-roughness < 5 Å), and a weakly adherent gold coating is applied to the polished surface. The gold layer is later separated from the mandrel and becomes the inner reflecting surface of the x-ray optic.

Advances in Mirror-Shell Replication.

The most serious issue in replication is that standard nickel electroforming intrinsically produces a shell with high internal stress (typically several thousand lb/in^2), causing the shell to deform after separation. In collaboration with researchers at the University of Alabama Center for Applied Optics, we developed a method for stress-free electroformed-nickel plating, using thin-membrane sensors to monitor stress during the nickel plating and to reduce the average internal stress to zero by controlling the plating current density.

End effects encountered during electroforming also presented a problem. The higher electric field at the sharp ends of the mandrel results in nonuniform nickel deposition. In addition, the plating extends over the end of the mandrel, thus preventing separation. For our early replicated optics, we machined the ends of the mandrel/optic combination to remove the offending material. Such an approach was unsatisfactory because it introduced significant contamination between the optic and mandrel during machining, and shortened the mandrel with each subsequent replication. To avoid this, we developed a three-part mandrel, comprising the principal mandrel and two end caps, each cap being ~1-in long. The entire three-part mandrel, rigidly bolted together, undergoes the usual diamond turning, electroless-nickel plating, polishing, and gold coating. Just prior to the final electroforming of the mirror shell, the three-part mandrel is disassembled and thin Teflon spacers are inserted between the end caps and the main mandrel. These thin, dielectric spacers do not alter significantly the electric field; the plating is uniform on either side of the discontinuity. However, the spacers do facilitate removal of the end caps after electroforming, leaving a mandrel/optic combination ready for separation.

The final step in producing a replicated optic is separation of the mirror shell from the mandrel, by cryogenically cooling the mandrel until differential contraction causes complete detachment from the nickel shell. Initially, we found it very difficult to separate the mirror shell without scratching the gold reflecting surface or the highly polished mandrel. Furthermore, the extremely cold optical surfaces condensed atmospheric water vapor, leading to surface contamination. To eliminate these problems, we designed and built a separation fixture which allows precise withdrawal of the shell from the mandrel. During the separation procedure, both the optic and the separation fixture are maintained in a clean, dry-air environment to avoid contamination.

The culmination of these process improvements is that we have successfully produced mirror shells from several mandrels. The best of these mandrels has an excellent surface (6-Å RMS micro-roughness), measured to be the same before and after replication.

X-Ray Test Results.

In January 1996, we x-ray tested two 1/10-scale AXAF-P6/H6 shells (replicated from the same mandrel), using MSFC's 100-m "stray-light" facility outfitted with commercial electron-impact x-ray sources. The blur introduced by the finite-size source and the finite distance is negligible (≈0.5 arc sec (")). To detect the focused image, we employed an x-ray-sensitive Charge Injection Device, with a 528 by 528 array of 28-mm pixels. Figure 164 shows an image at 8.0 keV. A preliminary analysis of the results of these tests (FWHM ≈8", HPD ≈27" at 8 keV) document a significant improvement over our previous efforts (table 12). Future research will be directed toward creating lighter-weight optics while maintaining or improving the angular resolution demonstrated here.

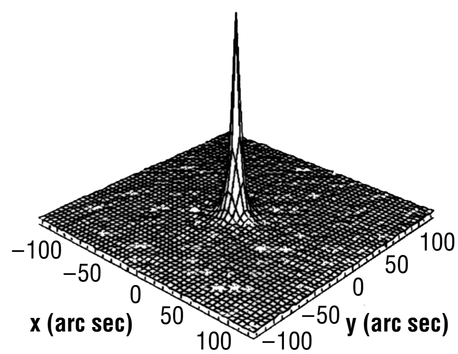

Figure 164.—Image at 8 keV of optic No. 1.

Table 12.—*X-ray test results.*

	4.5 keV	6.4 keV	8.0 keV
HPD (") Optic 1	15±2	—	27±2
HPD (") Optic 2	23±2	26±2	28±2

Related efforts include the development of extensive software tools to model all aspects of photon (and subsequent charged-particle) interactions within flight instruments. These programs have recently shown the importance of modeling photoelectron tracks in gas detectors if true response matrices are to be developed for instrument calibration.[5] They are also being used to develop software for analysis of data from the forthcoming SXRP[6] experiment, on which the x-ray astronomy group is collaborating.

As a complement to the above experimental program there is an active theoretical effort within the group. This work includes the calculation of high-resolution x-ray spectra from galaxy clusters through models for galaxy-cluster atmospheres. The goal of this research is to identify promising spectral diagnostics for cluster spectroscopy from x-ray observatories such as ASCA, AXAF and ASTRO-E. These diagnostics will help determine the basic properties of the cluster plasma, such as temperature, density and elemental abundances. Another goal of this research is to determine whether effects such as multiphase plasma flows, radiative cooling, or plasma shocks by cluster merging possess unique quantitative spectral signatures.

A large body of software has been developed, in support of the AXAF program, which has widespread application, for example, in the design of x-ray optics or the design and evaluation of imaging systems. One typical current application is the design of novel continuously graded multilayers for broad-band x-ray optics in the hard x-ray region. Such multilayers are currently being developed for MSFC under the Small Business Innovative Research Program and would be of use not only in astronomy, but in medical physics and such areas as x-ray photolithography.

Finally, also in support of the AXAF program, a technique has been developed for in-situ monitoring of surface contamination of x-ray telescopes.[7] This utilizes radioactive source to measure the reflectivity at several wavelengths and offers many benefits over the traditional technique of witness samples that accompany the optic and are examined at appropriate intervals.

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Sponsor: Office of Space Science

Biographical Sketch: Brian D. Ramsey received his Ph.D. in astrophysics from The University of Birmingham, England, in 1978. After a 5-year postdoctoral fellowship in Birmingham, he came to MSFC in 1983, and currently works in the x-ray astronomy group of the Physics and Astronomy division. His principal duties include providing support for the AXAF program, and overseeing the MSFC X-Ray Balloon Program and the developments of new instruments for x-ray and gamma-ray astronomy.

Martin C. Weisskopf received his Ph.D. from Brandeis University in 1969. From 1969 until 1977, he was at Columbia University—first as a research associate, and then as assistant professor of physics. In 1977, he came to MSFC to start the x-ray astronomy group and is currently senior scientist for x-ray astronomy at MSFC and project scientist for the AXAF mission.